This cyclone increased rapidly in intensity after leaving Montana, the central pressure falling below 29 inches over northern New England and the lower St. Lawrence Valley on February 26. Its further progress toward the east was blocked by an area of high pressure that covered Greenland and extended southeastward to the Azores at that time. Consequently it moved almost directly northward to the Hudson Strait region, reaching its greatest intensity near Fort Chimo where the barometer read 28.51 inches the evening of the 27th. By the morning of March 2 the center was near Ponds Inlet, Baffin Land, but rising pressure to the north and northeast and a change in wind direction aloft caused the center to shift southward to the western end of Hudson Strait by the morning of the 3d. Within 12 hours thereafter there was a decided decrease in pressure over Greenland and the center (29.11 inches) was near Upernivik, on the western coast of Greenland at 73° north latitude at 8 p. m. of the 3d. Passing rapidly eastward over northern Greenland and then turning toward the southeast, the center of this cyclone reached Sweden (28.74 inches) on the 6th and Leningrad, Russia, (28.74 inches) on the 7th. The rate of movement lessened greatly and the cyclone decreased in intensity while moving almost directly eastward over northern Russia and Siberia during the next three days, after which its path turned more to the southeast and it was central some distance northwest of Irkutsk on the 12th. At this time a strong anticyclone that was spreading rapidly southward and southeastward from the Spitzbergen-Nova Zembla region seemed to furnish the impetus that caused a rapid southeastward movement of the cyclone, the center of which was over the region northwest of Korea the morning of the 13th. By the 14th it was near Tokyo, after which the cyclone moved quite rapidly across the Pacific Ocean, reaching the British Columbia coast by the 19th and the northern Lake Region by the 21st. This cyclone became occluded during the night of the 20th–21st and it diminished rapidly in intensity as it advanced eastward to the Gulf of St. Lawrence during the next two days. By the 22d a solid wall of high pressure surrounded the now very weak cyclone and it finally disappeared on the 23d.

METEOROLOGICAL NOTES ON THE FORMATION OF ICE ON AIRCRAFT

By C. G. ANDRUS

[Cleveland Airport, Ohio, December 15, 1929]

Throughout the entire gamut of weather activities, fog and ice are the greatest dangers to air transport. Of these dangers either by itself is a hazard against which all possible precautions are taken. Fog is still a bewildering thing to penetrate at modern airplane speeds—beacons, radio, instruments, and an experienced hand at the stick notwithstanding. When to this danger, bad in itself, is added that of icing up, the hazard is, indeed, great. To accumulate ice it is generally necessary to fly "blind" through clouds, and flying through cloud masses is equivalent to flying through dense fog. There is, however, a great difference between the effect of fog and that of ice upon flight. Fog bewilders, obscures, distorts, and blinds the pilot's vision, but flight as a mechanical process goes on, requiring only expert guidance. But ice increases drag, distorts wings, sets up terrifying vibrations, and may even destroy the aircraft; it is not a navigational difficulty so much as a matter of maintaining flight and retaining control of the craft; in the last analysis a matter of ability to stay up. Hence, its great danger and its record of disastrous results.

In the winter of 1926–27 pilots flying between New York and Cleveland related astonishing experiences with ice, which at that time was considered as a matter of contact with snowflakes and freezing rain. Experiments farther South were going on, indicating a tendency to freeze ice on the planes in temperatures a few degrees below freezing. The following winter previous experiences were corroborated, and it was clearly indicated that certain conditions hitherto only suspected produced ice and were especially prevalent near the Great Lakes. A previous discussion (1) deals with the reports of the pilots and the conclusions drawn. Many students of the subject were prone to believe that the surprisingly low temperature reports were unacceptable and theoretically unlikely, although there was persistent repetition of the reports of temperatures far below freezing, all however obtained from personal observations or from none too reliable instruments

It was but a short step to the self-recording aerograph. From it can be obtained verifiable records of temperature, humidity, and altitude; if properly exposed there can be little question as to the accuracy of its records. Thus, last winter (1928–29) plans were made by the Weather Bureau to mount two of these, when opportunity offered, on the wings of the transport planes of the National Air Transport (Inc.), mail contractor carriers, who volunteered the use of the planes between Cleveland and New York, the cooperation of its personnel and an offer to construct special streamlined containers to be made fast to the wings. These containers were mounted so far from the motor that no influence of heat from that source could reach them. The pilots told at what time ice was taken; the aerograph showed what conditions then existed. The initial offensive to track down this "bete noir" of flying has yielded recorded aerograms which wholly support the earlier personal accounts of a noninstrumental nature.

Out of many flights, made between February 6 and mid-April, 1929, eight yielded records while the carrier planes were taking ice. Some of the instances were mild, others moderately severe, but of course none was disastrous. Collectively, they show agreement on several features, (1) subfreezing temperatures down to at least −23 C. (−10 F.); and (2) relative humidities above 90, as prerequisites for taking ice. In the vicinity of 100 per cent humidity the accumulation is faster than in conditions less saturate. When the temperature is below freezing its reading is most useful to determine how great the quantity of moisture may be at saturation. Owing to the higher amount of moisture per mass at the higher temperatures, it appears that the ice accretions of the planes would be greatest at temperatures just below freezing tapering slowly as temperatures reduce. The process appears to be the same throughout, the mass alone varying.

The collection of ice at relative humidities under 100 per cent warrants comment. In forging through clouds at airplane speeds the aircraft and the aerograph may pass rapidly through varying densities of clouds. The air is usually turbulent in clouds, and the intensity of the opaque curtain of gray-white is usually noted by fliers as varying in rapid fashion. It appears that within few clouds are there homogeneous masses of saturated vapor, but rather a mixture of saturated vapor and slightly less than saturated air, depending on the vertical activity of turbulence. An average relative humidity in the high nineties results in many cases. Within air masses of variable humidities, an airplane traveling through such a condition would accumulate, during the immersions in full saturation, more ice than could be dissipated in the intervals between such immersions; consequently the accretions grow in size. Occasionally are found short immersions in 100 per cent humidity conditions, but few planes have been able to stay long in such conditions.

Some general conclusions may be drawn from the instrumental graphs. Ice is taken under a variety of conditions. Certain atmospheric states are requisite; there are also certain states which render impossible the collection of ice. Because the latter may be briefly stated, they are given first, as follows: Air masses at temperatures exceeding the freezing point of water; air masses not showing vapor in visible form; air masses containing utterly frozen vapor particles with temperatures below the freezing point of water.

Conversely, ice may be taken on the plane while it is immersed in visible moisture at temperatures below the freezing point, unless the moisture is wholly in the form of ice spicules and "dry" (of water) snowflakes. Clouds of water droplets subcooled below freezing are the most dangerous and most common of ice-creating conditions. They may or may not be attended by precipitation. It is noteworthy that only a small percentage of the clouds of the sky are composed of "dry" clouds; that is, clouds whose particles are crystalline and devoid of watery moisture. This may seem startling, but outside of the cirrus level and except for a limited frequency of pall-type clouds of winter there have been many observed facts pointing to the droplet structure of clouds even at high levels. Iridescence, fogbows, coronae, and cloud rainbows (observed from above the clouds) all depend for their being on fine droplets of unfrozen water.

For some reason, the elucidation of which will be outside the realm of this paper, these droplets remain in a colloid or liquid state far below the freezing point; perhaps surface tension and suspended crystallization are responsible, but the facts remain and their explanation need be but touched upon here. An airplane proceeds through such a cloud, cracking against its leading edges many such droplets, which forthwith crystallize fast to these edges. Upon these crystalline coats others crystallize, as upon the original wing or structure surface and thereupon an accumulation is under way. The growth will be continuous as long as the cloud and plane are present in the proper state of action. The airplane or its parts possess no inherent cold which condenses moisture and freezes it, on the order of the "sweating" of a glass of ice-cold water on a summer day. The airplane simply provides what nature demands everywhere, that base for crystalline birth and growth which has been hitherto lacking in that particular cloud. This is the condition which is the most dangerous of those which may produce ice, because of its quick action at a time when the pilot is already in the difficulties of blind flying.

Freezing rain is another condition through which an airplane may fly and take on ice. Freezing rain is rare, however, in comparison with subcooled cloud frequencies, and is less likely to occupy a wide extent of territory, geographically or vertically. Here and there it develops as precipitation below clouds which are generally warm. Raindrops are either directly condensed as such, or are the result of the melting of snowflakes. Falling farther down they reach a cold substratum of air near the ground, in which they freeze or are reduced to subfreezing temperatures. The former action makes sleet; the latter, freezing rain and glaze. An airplane passing through the stratum in which the subcooling is proceeding will take ice, usually in the form of a rough clear coat with many protuberances. If some sleet is mixed with the water drops these may hold this sleet as it strikes the plane and a mixed coat of frozen rain and imprisoned sleet results; this is highly hazardous.

Moist snowflakes stick to any surface they strike, and this is true of airplane surfaces. The pressure of wind and the rapidity of the motion permits a large collection to form and solidify on the plane. Occasionally rain mixed with the snow is imprisoned on the leading edge and the slush reduced to ice to form an accretion which is rough and massive. The fact that sticky substances are somethimes applied to wings to prevent ice introduces a feature in the snowflake type of ice which is conducive to help rather than hinder the ice, for the sticky substance then actually speeds up the action.

The ice problem is attracting widespread and expert attention. Its solution by many means has been proposed and devices and means are constantly being evolved, by which the icing up of airplanes may be rendered harmless or impossible. The soundest means, that of avoidance, can not always be adopted as conditions must be recognized well in advance to assure avoiding those suitable for ice, and airplanes occasionally are caught unawares by sudden changes unanticipated. Nevertheless, avoidance is the best known method of reducing disasters in this field. Among the methods proposed may be named a few general types, whose chief aim is to prevent the ice from forming, or to rid the surfaces of it once it has formed. They are chemical, mechanical, or thermal. Briefly, the chemical method for lowering the freezing point of water and rendering the water of the droplets slow to form hard crystallization will solve the problem. Included in the chemical method are radioactive action, osmosis, slow dilution, and other schemes. The mechanical means range from flexible coving of the wings to guards and sprays. Under this head may be placed such means as highly polished surfaces and proposals to produce a hard surface which will be too repulsive to crystals to permit collections. Thermal methods embrace means for heating, from exhaust heat or otherwise, those portions of the wings which are subject to the accumulations. All these methods have stout champions and attractive features. Possibly the most conservative statement a meteorologist could make would be to the effect that nature operates with an abundance of energy in meteorological activities, and any method must not be merely acceptable in a laboratory test but should be tried in the larger laboratory of the free air.

Avoidance of ice conditions entails study of the weather map, apprehension of dangerous conditions from ground observations, and comprehension of the relationship between topography and weather over the route of flight. In the region near the Great Lakes ice conditions sometimes surprise the tyro at forecasting, and he is likely to predict fair weather for a period which will have pronounced ice-formation features. A fair example of such a condition occurred November 28 to 30, 1929, when a marked change to colder was drawn across the lower Lake region in the rear of a pronounced LOW. The temperature in the "polar front" fell to nearly zero and as the vapor "steaming" off Lake Erie was mixed by turbulence and adiabatic cooling, great cumulus and strato-cumulus clouds developed and extended to great heights. Occasional outbreaks of thunder were reported. The entire process resulted from great difference between the temperature of the Lake surface and the cold air blowing southeastward over it. The thunder, snow and the ice-formation conditions resulting are repeated each time cold air passes over the relatively warm lake surface, and maintains a temperature below freezing. What is normally the clearing side of the retreating LOWS thus becomes the danger zone for ice in the vicinity of the Great Lakes. Apparently the greater the horizontal temperature gradient to the north of the Lakes and the lower the dew point in that section the greater will be the scope of the condensation on the south side of the Lakes in northwest winds.

Besides the strip of hazardous territory immediately bordering the Lakes another strip is usually found on the western slopes of the Appalachian Highlands in Pennsylvania, and New York. Here the southeastward bound air is again chilled, this time through mechanical raising by the hills. The clouds in such cases form on the hills, obscuring all high ridges, and rendering it necessary to fly through these clouds in order to get over the ridges, and an intensely dangerous condition exists, far worse than may be found over the more level terrain near the Lakes where a small margin between ground and clouds is a safety zone in many instances.

In theory, it may be assumed that the dew point at the ground must be below freezing to permit ice to form on airplanes in the base of the lower clouds over that ground, especially in turbulent conditions. Practically, it is believed that this holds forth some index to dangerous ice conditions, and later it may be possible to advise caution only in areas where ground dew points are below freezing or tending rapidly to attain values below freezing. If there are clouds in the sky under turbulent conditions, their altitude may be calculated by assuming the dry adiabatic lapse rate of temperature corrected for expansion to be in effect and from this reckoning the altitude required to correspond to the difference between dry-bulb temperatures and dew-point temperatures. Both the temperature and altitude of the cloud bases are then available, and these may be referred to surrounding terrain to determine whether clearance may be had over near-by ridges. Another valuable assumption is that the temperature of the base of the clouds will furnish an index so the added altitude necessary to reach temperatures below freezing if this cloud base is above freezing. Such an index is useful in permitting short immersions in clouds to hurdle mountain ridges, if only a short climb is necessary. The lapse rate of temperature for the wet or condensation stage is used. Tabulations of these three sets of factors have just been prepared andtheir trial during the coming winter months is expected to indicate whether they furnish much genuine help to the pilots.

When planes are equipped with readable thermometers and hygrometers, and the meteorologist is armed with many more supporting facts for his few favored assumptions, the question of avoidance will be easier of solution whatever results are obtained by those who labor to develop preventive means. In addition to the two aerographs used last year between Cleveland and Hadley Field, N. J., two more are available this winter, and will be used between those points and between Chicago and Cleveland and Kansas City, and should furnish further light on an interesting and complicated phenomenon.

REFERENCE

(1) "The Problem of Combating Ice Accumulation," by C. G. Andrus, Aviation, Vol. XXIV, No. 16, of April 16, 1928.

NOTES, ABSTRACTS, AND REVIEWS

Henry Joseph Cox, 1863–1930.—In the death of Prof. Henry Joseph Cox at Chicago on January 7, 1930, the Weather Bureau, Department of Agriculture, loses a weather forecaster of wide experience and mature judgment and an executive of rare ability.

Professor Cox was born at Newton, Mass., April 5, 1863, son of Thomas and Hannah Perkins Cox; he attended the primary schools of his native city, was graduated from Harvard University with the A. B. degree in 1884, and received the honorary A. M. degree from Norwich University in 1887, and the degree Sc. D. from the same institution in 1914. He married Mary, daughter of C. C. Cavanagh and Martha Cavanagh in 1887, and is survived by his wife and two sons, Henry Perkins and Arthur Cavanagh; a third son, Paul Greenwood, was killed in action at Soissons, France.

He entered the Weather Bureau (then the Signal Service) on August 1, 1884, and after completing a five months' course in training at Fort Whipple, Va. (now Fort Myer), was assigned to the Chicago station as an assistant observer in January, 1885; in August of the same year he was transferred to the Boston, Mass., station where he served until November 16, 1886; on November 17 of that year he opened the Weather Bureau station at Northfield, Vt., and served as its first official in charge until April 26, 1888; he was then transferred to charge of the New Haven, Conn., station and continued in charge until his appointment as a local forecast official in October, 1894. He was then assigned to the Chicago station, the second time, but now as an assistant to the local forecaster in charge of that station. In 1898, on the creation of the north central forecast district, Cox was placed in charge and he continued in that position until his death; his forecasting activities cover, therefore, a period of 35 consecutive years, 31 of which were as a district forecaster, a record not surpassed by any other Weather Bureau forecaster.

As an official in charge of station, Cox's dominating idea was service to the public—a service that he placed on a very high plane and for which he never had occasion to apologize. His intense loyalty to that service was perhaps the outstanding feature of his administration of the Chicago station. Like many other leaders of men, he inspired his assistants, both by example and precept, to put forth their best efforts. He was an outspoken and an uncompromising enemy of all forms of quackery that by insidious methods sought to creep into the art of weather forecasting.

In his contacts with the general public Cox sought to ally himself with commercial organizations and especially with educational and scientific institutions. While at Northfield, Vt., he inaugurated a course in meteorology in Norwich University, located at that place.

While at Chicago his relations to the Geographic Society of that city were intimate and helpful; in collaboration with Armington, his first assistant, he prepared a monograph on the weather and climate of Chicago (Bull. 4 of the society). He was a past president of the society and the recipient on December 28, 1928, of the Geographic Society of Chicago's gold medal awarded